List of Figures

Chapter Seventy-eight

HIGHWAY LIGHTING

78-1.0 GENERAL

The purpose of highway lighting is to provide a safe and comfortable environment for the night-time driver. Due to the voluminous nature of highway lighting system design, it would be impractical for this chapter to present a complete highway lighting design guide. For additional design information, the designer is encouraged to review the latest edition of the references listed in Section 78-1.01. The intent of this chapter is to provide the user with a synopsis of the highway lighting design process and to present INDOT's criteria, policies and procedures on these issues.

78-1.01 References

For additional information on highway lighting, the designer may review the publications as follows:

1. *An Informational Guide for Roadway Lighting*, AASHTO;
2. *Roadway Lighting Handbook*, FHWA;
3. *Roadway Lighting Handbook*, Addendum "Designing the Lighting System - Using Pavement Luminance," FHWA;
4. *Roadway Lighting*, RP-8, Illuminating Engineering Society (not used on INDOT projects);
5. NCHRP Report No. 152, *Warrants for Highway Lighting*, TRB (not used on INDOT projects);
6. NCHRP Report No. 256, *Partial Lighting of Interchanges*, TRB (not used on INDOT projects);
7. Chapter Forty-nine, "Roadside Safety," *Indiana Design Manual*, INDOT;
8. *Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals*, AASHTO;

9. INDOT *Standard Drawings*, INDOT;

10. INDOT *Standard Specifications*, INDOT;

11. National Electrical Code; and

12. National Electric Safety Code.

78-1.02 Definition of Terms

The following defines the more commonly used terms in highway lighting.

1. Average Maintained Illuminance. The average level of horizontal illuminance on the roadway pavement when the output of the lamp and luminaire is diminished by the maintenance factors; expressed in average lux for the pavement area.

2. Candela. The unit of luminous intensity.

3. Candela per Square Meter. The unit of photometric brightness (luminance). The unit is equal to the uniform luminance of a perfectly diffusing surface emitting or reflecting light at the rate of one lumen per square meter or the average luminance of any surface emitting or reflecting light at that rate.

4. Effective Mounting Height. The vertical distance between the foundation of the light standard and the center of the light source in the luminaire.

5. Glare. The optical sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted and which causes annoyance, discomfort or loss in visual performance and visibility.

6. Illuminance. The density of the luminous flux incident on a surface. It is the quotient of the luminous flux by the area of the surface when the latter is uniformly illuminated.

7. Lamp Lumen Depreciation Factor (LLD). A depreciation factor that indicates the decrease in a lamp's initial lumen output over time. For design calculations, the initial lamp lumen value is reduced by a lamp lumen depreciation factor (LLD) to compensate for the anticipated lumen reduction.

8. Longitudinal Roadway Line. A line along the roadway parallel to the curb or shoulder line.

9. <u>Lumen</u>. A unit of measure of the quantity of light.

10. <u>Luminaire</u>. A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and to connect the lamps to the power supply.

11. <u>Luminaire Dirt Depreciation Factor (LDD)</u>. A depreciation factor that indicates the expected reduction of a lamp's initial lumen output due to the accumulation of dirt on or within the luminaire over time.

12. <u>Luminance</u>. The luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction.

13. <u>Lux</u>. The illuminance on a surface one square meter in area on which there is uniformly distributed a light flux of one lumen, or the illuminance produced on a surface for which all points are at a distance of one meter from a uniform point source of one candela.

14. <u>Maintenance Factor (MF)</u>. A combination of light loss factors used to denote the reduction of the illumination for a given area after a period of time compared to the initial illumination on the same area (MF = LLD x LDD).

15. <u>Mounting Height</u>. The vertical distance between the roadway surface and the center of the light source in the luminaire.

16. <u>Nadir</u>. The vertical axis which passes through the center of the luminaire light source.

17. <u>Spacing</u>. The distance in meters between successive lighting units.

18. <u>Transverse Roadway Line</u>. Any line across the roadway that is perpendicular to the curb or shoulder line.

19. <u>Uniformity Ratio</u>. The ratio of average maintained lux of illuminance on the pavement to the maintained lux at the point of minimum illuminance on the pavement. A uniformity ratio of 3:1 means that the average lux value on the pavement is three times the lux value at the point of least illuminance on the pavement.

<u>78-1.03 State and Local Responsibilities</u>

The following describes the responsibilities between the Department and local government agencies for lighting installations along State-maintained highways.

1. <u>INDOT Jurisdiction</u>. The Department may illuminate any portion of a State, U.S. or Interstate highway outside incorporated city or town limits that meet the warranting conditions provided in Section 78-2.0. INDOT will typically not provide illumination inside city or town incorporated limits, except along Interstates.

2. <u>Local Jurisdiction</u>. Local governmental agencies may install lighting along State highways within their jurisdictional limits provided the agency finds sufficient benefit in the form of convenience, safety, policing, community promotion, public relations, etc. Desirably, each local agency will develop appropriate warranting guidelines for installing lighting. If the city or town has not developed warrants, the Department warrants in Section 78-2.0, or those listed in the references in Section 78-1.01, should be considered. The local agency will be responsible for installing, maintaining and operating these lighting facilities. All plans for lighting State highways within jurisdictional limits must meet Department criteria and must receive INDOT approval through a formal agreement prior to installation. All plans should be submitted for review to the Lighting Unit within the Traffic Design Section.

3. <u>Installations</u>. Installations by the Department will typically be done under the Department's normal programming and contracting procedures. These installations, however, may be performed through agreements with utility companies.

4. <u>Operations</u>. For all locations where the Department is responsible for paying the energy costs, an agreement must be negotiated between the local utility company and the Department for payment of the electrical current. The current may or may not be metered. All bills should be submitted through the District for payment.

5. <u>Maintenance</u>. Maintenance of the Department's lighting systems may be furnished by agreement with the local utility company, by independent lighting contractors or by trained INDOT personnel.

6. <u>Agreements</u>. All lighting agreements for the Department's lighting systems should be prepared according to INDOT agreement policies. According to Indiana Code (IC, 8-23-22-2, and amendments thereto), the Department is required to enter into an agreement for sharing the utility costs.

7. <u>Existing Systems</u>. Where an agreement between INDOT and the local agency on maintenance and operation of an existing lighting system along State-maintained highways cannot be resolved, the following will apply:

    a. If a system installed by the Department is annexed into the city or town corporate limits and the local agency does not agree to take over the maintenance and operation costs, the system should be considered for removal if a cost analysis shows such action to be cost effective. A removal study as defined in Section 78-2.10 should be conducted.

b. If the system was installed by the local agency and the local agency is no longer willing to pay for the operation and maintenance costs, INDOT will determine if the system is warranted. If it is warranted and is outside the incorporated limits, the Department may take over the responsibilities for maintaining and operating the system. If the system is not warranted, the local agency may be requested to remove the system. If the local agency will not remove the system, the Department may remove it according to the provisions in Section 78-2.10.

c. If the system was installed in accordance with an agreement entered into between the Department and local governmental agency and the agency is no longer abiding by the stipulations of the agreement, the Department may conduct a study to determine if the system is warranted. If continuation of the system is not found to be cost effective, INDOT may remove it according to the provisions in Section 78-2.10.

8. Other Construction Projects. Where a proposed construction project (e.g., roadway reconstruction project) is within the city or town incorporated limits, the following will apply relative to lighting.

a. If the existing lighting system is owned by the local agency and the project requires the system to be relocated, INDOT will be responsible for all relocation expenses.

b. If the existing lighting system is owned by a utility company and the project requires the system to be relocated, the utility company will be responsible for all relocation expenses.

c. If there is no existing lighting and it is requested by the local agency, INDOT will include the lighting system in the project if the local agency agrees to pay for all installation costs and will take responsibility for the operation and maintenance of the system.

d. If the existing luminaire arms are mounted on utility company poles and the lighting hardware is owned by the local agency, INDOT will be responsible only for all relocation expenses associated with the lighting hardware, if requested by the local agency. No upgrades in the existing lighting would be accomplished under this option.

78-1.04 Lighting Studies

If a request is made for a new lighting installation along a State-maintained highway outside of the city incorporated limits, the following procedure should be employed.

1. Lighting Request. The local agency or other local group seeking the lighting system is required to submit a request to the district office petitioning the Department to consider the installation of a new lighting system along the State highway.

2. Lighting Study. The district office will conduct a study to determine if the request justifies further action. Each lighting study report should contain a copy of the Highway Lighting Accident Warrant Analysis.

3. Programming. If the location warrants lighting and it is outside the town or city corporate limits, the District Office will request the Division of Planning to initiate a project to provide lighting at the location.

78-2.0 WARRANTS

Providing lighting along all highways is not practical or cost effective. The district office will be responsible for determining if the lighting system is economically justified along State-maintained highways. It is generally the Department's practice to only provide lighting if there is an average of seven night accidents per year, and the night-to-day ratio of accidents is greater than 0.5. A blank Highway Lighting Accident Analysis Worksheet is shown as Figure 78-2B. Local officials may determine the feasibility of providing lighting within city or town limits. Any location which meets these warrants does not obligate INDOT to provide funding for the requested highway lighting project. INDOT's objective is to identify those roadways which should be considered in the process of setting priorities for the allocation of available funding to roadway lighting projects. For a lighting system to be considered, it should meet the warrants provided in the following sections.

78-2.01 Freeways

Where warranted, INDOT is responsible for providing highway lighting along all Interstates and State-maintained freeways outside of city and town corporate limits. Cities and towns are responsible for lighting along freeways, other than Interstates, which are within the corporate limits. Continuous freeway lighting (CFL) should be considered where one or more of the following warrants are met.

1. Accidents. CFL should be considered where there are a significant number of nighttime accidents that can be attributed to the lack of lighting and where it can be supported by a cost-effective analysis.

2. Nearby Development. CFL should be considered, for a length of 3.0 km or more, where the freeway passes through a substantially developed suburban or urban area and where one or more of the following conditions exist.

   a. the nearby local traffic operates on a street system that has some form of complete street lighting and which has some parts that are visible from the freeway;

   b. the freeway passes through a series of developments such as residential, commercial, industrial and civic areas, colleges, parks, terminals, etc., that have roads, streets and other areas that are lighted;

   c. separated cross streets, both with and without connecting ramps, are within 1 km of each other and are lighted as part of the local street system; and/or

   d. the freeway cross section elements (e.g., medians, right-of-way) are substantially narrower than desirable widths used for rural sections due to high right-of-way costs and adjacent developmental restrictions.

3. Interchanges. CFL should be considered where 3 or more successive interchanges are illuminated and have an average spacing of 2.5 km or less between them. Where CFL is provided through the interchange, complete interchange lighting should also be provided. See Section 78-2.02 for additional information on interchange lighting.

78-2.02 Interchanges

Interchange lighting can consist of either complete interchange lighting (i.e., all ramps, the mainline, and the cross street are lighted) or partial interchange lighting (e.g., gores, intersection). The Department's practice is that, once it has been determined that continuous freeway lighting is warranted, then complete interchange lighting should also be provided. Interchange lighting along unlighted freeways should be considered where the following conditions are met:

1. Accidents. Lighting may be warranted where there is a significant number of nighttime accidents that can be attributed to the lack of lighting and where it can be supported by a benefit/cost analysis. Once lighting is considered warranted, the choice between complete and partial interchange lighting will typically be determined according to ramp volumes. Complete interchange lighting will typically be provided where the total current average nighttime volume of all ramp traffic entering or leaving the freeway within the

interchange area exceeds the limits of the values presented in Figure 78-2A, Minimum Volumes for Complete Interchange Lighting. If only partial lighting is considered cost effective, then only partial lighting should be provided regardless of the traffic volumes.

2. Nearby Development. Complete interchange lighting should be considered where nearby development, commercial or industrial, is lighted and is located within the immediate vicinity of the interchange or where the crossroad approach legs are lighted for 1 km or more on each side of the interchange.

3. Ramp Terminals. The intersection of ramps and the crossroad at interchanges may be considered as separate intersections or as part of the interchange depending on the condition and location of accidents.

78-2.03 Warrants for Streets and Highways Other Than Freeways

Where warranted, the Department is responsible for installing and maintaining lighting systems on State-maintained highways outside city or town corporate limits.

Lighting should be considered where a highway section or intersection has a significant number of accidents (an average of at least seven nighttime accidents per year) that can be attributed to the lack of lighting and where the night-to-day accident ratio is greater than 0.5. The lighting system must also be shown to be cost effective using the Highway Lighting Accident Warrant Analysis Worksheet shown as Figure 78-2B. Typical highway sections where lighting should be considered are those with a relatively high potential for numerous accidents, such as sections with numerous driveways, channelized islands, significant commercial or residential development, a high percentage of trucks and/or geometric deficiencies.

Where a State-maintained highway intersects with or closely parallels local streets with existing lighting or which may have future lighting, provisions should be made for possible future illumination on the State-maintained highway.

78-2.04 Highway Sign Lighting

Signs may be internally illuminated or externally illuminated by a direct source. Street or highway lighting does not satisfy the requirements for sign illumination. Section 75-2.03 provides the Department guidelines for sign illumination.

78-2.05 Rest Areas

Lighting will typically be provided for all areas within the rest area that have pedestrian activities. Rest area ramps are generally also lighted, especially if continuous lighting is provided on the freeway. Highway-type light standards and luminaires should be used to light the parking areas as well as the ramps.

78-2.06 Truck Weigh Stations

All permanent truck weigh stations should be lighted where weighing will occur after daylight hours. Highway-type light standards and luminaires should be used to light the weighing areas, parking areas, speed change lanes and ramps. Lighting may be provided for the sign preceding a truck weigh station which indicates that the station is open or closed.

78-2.07 Bridge Structures

The designer should consider the following in determining the need for lighting on bridge structures.

1. Lighted Approaches. Provisions should be provided for placing lighting across or under bridges where one or both approaches have or are planned to have lighting. Ownership of the lighting will be determined in the same manner as for roadways.

2. Geometrics. Lighting may be considered for long, narrow bridges even though the approaches are not lighted. Lighting should be considered where there is unusual or critical roadway geometry under or adjacent to the underpass area.

78-2.08 Tunnels

The lighting of tunnels should be according to the criteria presented in the AASHTO *An Informational Guide for Roadway Lighting.*

78-2.09 Other Locations

In addition to the above, lighting should be considered at the following locations.

1. commuter park-and-ride lots,
2. bikeways,
3. walkways, and
4. other pedestrian facilities.

The need for lighting at these locations will be determined on a case-by-case basis.

78-2.10 Reduction or Removal of Lighting

Where an existing highway lighting system is no longer warranted, feasible or cost effective, it should be considered for reduction in the lighting level or be removed. Where light levels are reduced, they should not be reduced below the criteria presented in Section 78-6.0. Prior to reducing lighting or removing the system, an engineering investigation will be required. Concurrence by the Central Office Division of Design and approval by the Commissioner of the Indiana Department of Transportation will be required. If Federal-aid funds were used for the original installation and the project is on the National Highway System and is not exempt from FHWA oversight, a copy of the report should be submitted to the FHWA.

When determining whether an existing lighting system should be removed or the lighting reduced, the designer should consider the following.

1. Freeway Lighting. Remove or reduce continuous freeway lighting where a cost analysis shows that such action would be cost effective. The cost analysis will be similar to the one prepared for the installation of a new lighting system. However, this study will need to consider the increase in accidents and cost to remove the system. Assume a 50 percent increase in nighttime accidents over a period of three years for analysis purposes.

2. Interchange Lighting. Reduce complete interchange lighting to partial interchange lighting where the average ramp volumes fall below those shown in Figure 78-2A, Minimum Volumes for Complete Interchange Lighting. An engineering analysis will be required to determine the extent of lighting reduction. Removal of complete or partial lighting will require a cost analysis to determine the cost effectiveness of removing the lighting system. Assume a 50 percent increase in nighttime accidents for analysis purposes.
3. Non-Freeway Lighting. Where lighting is no longer warranted on a non-freeway section, a benefit/cost analysis should be conducted to confirm that the lighting is no longer warranted. Section 78-1.03 describes the procedures for removal of lighting when the local agency no longer can or is willing to pay the maintenance and operation costs for the lighting system.

4. Sign Lighting. Removal of sign lighting may be considered where the traffic volumes for the ramp fall below those shown in Figure 75-2A. A minimum of three traffic volume counts should be conducted to justify the removal of lighting. Counts should not be taken less than 9 months apart nor more than 2 years. The counts should show either steady or declining nighttime volumes. Counts from other studies may be used.

5. Obsolete/Sub-Standard Systems. Where it has been determined that a lighting system is obsolete or sub-standard or it is beyond its useful service life, it should be removed, replaced or modified. An engineering investigation should be conducted to determine the appropriate action. If removal is considered, local input should be included in the investigation. A new replacement system should only be installed if it meets the warrants for a new system. Current accident data may be used for the analysis. However, the data should be adjusted to reflect the expected increase in accidents if the system is removed.

To study the effects of removing or reducing lighting, the Department may turn off part or all of the system. This may only be performed after an engineering analysis has been conducted to determine the expected effect of turning the lights off. This study period should not be less than one year or more than four years. After the study has been completed, the system may be either re-energized or removed.

After the decision has been made to remove or reduce the level of highway lighting, the lights should be turned off but left in place for a period of at least one year and no longer than four years. For all roadway lighting systems, an accident analysis study will be required during this time period to determine the effects of the reduced lighting. A final cost analysis will be required with the updated accident and capital-improvement data. All system removals will be accomplished by either State forces or by contractors under a project.

78-3.0 LIGHTING EQUIPMENT

A variety of options are available to the designer when selecting luminaire equipment that will meet the desired design criteria. Figure 78-3A, Typical Luminaire, provides an illustration of the various parts of the lighting standard and luminaire. In addition to the INDOT *Standard Drawings* and the INDOT *Standard Specifications,* the following sections provide guidance on INDOT's preferred lighting equipment.

The designer should ensure that the selected equipment meets standard hardware designs. Specialized equipment and designs can significantly increase the installation and maintenance costs, thereby reducing the cost effectiveness of the lighting system.

78-3.01 Foundations

When determining the foundation design, the designer should consider the following:

1. Material. All foundations for permanent installations should be made with Class A concrete. Foundations may be either cast-in-place or precast.

2. Design. The INDOT Standard Drawings provide the design details for depth, width, reinforcing, etc., for both conventional and high-mast light standards. For high-mast foundations, a soil survey may be required to determine if additional support may be required.

3. Placement/Grading. The INDOT Standard Drawings and Section 78-6.05 provide the Department's criteria for the placement of light standards relative to the roadway and ditch lines. They also provide criteria for grading around the light standard foundation.

78-3.02 Light Standards (Poles)

A major factor in highway lighting design is the selection of the luminaire and the mounting height. Higher mounting heights usually reduce the number of light standards required. The INDOT *Standard Specifications* and the latest edition of the AASHTO Standard Specifications for Structural *Supports for Highway Signs, Luminaires and Traffic Signals* provide the Department's criteria for light standards. The following describes the light standards commonly used by the Department:

1. Conventional. This pole type is typically used for lighting most highways. These poles have mounting heights ranging from 9 m to 15 m. INDOT's typical practice is to use a light pole with a mounting height between 12 m and 15 m. The recommended minimum mounting height is 12 m.

2. High Mast. High-mast poles can range from 24 m to 60 m. This pole is an excellent choice where there is a large area that requires lighting (e.g., interchanges). The use of high-mast lighting and higher wattage lamps greatly reduces the number of poles, yet retains the quality of the lighting. The designer should consider using high-mast lighting wherever practical.

3. Materials. Light standards for permanent installations are typically made of galvanized steel, stainless steel or aluminum. Wood poles are normally used for service poles or for temporary lighting (e.g., in construction zones). High-mast poles are made from weathering steel. The INDOT *Standard Specifications* provide the Department's criteria for all light standards used by INDOT.

4. Bases. Unless otherwise protected, a breakaway base should be provided for all light poles within the clear zone along rural and high-speed urban highways. However, where pedestrians are commonly present, breakaway designs should not be used. Section 78-6.05 provides additional criteria on the appropriate application of where to use breakaway or non-breakaway bases. All breakaway bases shall meet the breakaway criteria set forth in the AASHTO *Standard Specifications for Structural Supports for*

Highway Signs, Luminaires, and Traffic Signals. Typical base types include the following:

a. Breakaway Transformer Base. Transformer bases consist of an aluminum apron between the concrete foundation and the base of the pole. The breakaway transformer base is designed to be struck by a car's bumper. When hit, the base deforms and breaks away. All wiring inside the base must also be connected to the breakaway device. INDOT's practice is to use the cast aluminum transformer base.

b. Non-breakaway Steel Transformer Base. Steel transformer bases are similar in design to aluminum bases. However, they do not meet the AASHTO breakaway criteria. Section 78-6.05 discusses the appropriate locations where breakaway designs are not required.

c. Breakaway Support Couplings. Breakaway support couplings are aluminum connectors or sleeves which are designed to shear when the pole is hit. The bottom of the coupling is threaded onto the foundation anchor bolts, and the light standard is attached to the top of the coupling. Four couplings are used with each light standard. Support couplings are typically 120 mm long.

d. Anchor Base. Anchor bases are typically metal plates which are welded to the bottom of the luminaire support. The plate allows the post to be bolted to the foundation without an intermediate breakaway device or to a breakaway coupling, slip plate or transformer base.

5. <u>Structural Designs</u>. All lighting standards must meet the structural design criteria presented in the INDOT Standard Specifications including the criteria for wind loading, maximum horizontal deflection, maximum stresses, luminaire loads, material strengths, welds, bolts, etc.

6. <u>Effective Mounting Height</u>. Light standards must be constructed so that they provide a luminaire mounting height above the roadway pavement as shown in Figure 78-3A, Typical Luminaire. After determining the mounting height, the appropriate pole length can then be determined.

78-3.03 Mast Arms

Mast arms allow placement of the light source near the edge of the travel lane. The use of longer mast arms is recommended, although the initial costs may be higher. Longer mast arms allow the poles to be placed farther from the traveled way, thus providing a safer roadside environment. Otherwise, the use of longer mast arms may have a negative effect on the loading capabilities of the base. In addition to the INDOT *Standard Specifications*, the following provides information and design guidance on the typical mast arms used by INDOT.

1. Materials. Mast arms are typically made from the same material as the light standard.

2. Aluminum Mast Arms. The following should be used to determine the appropriate mast arm type.

    a. Less than 2.4 m. Mast arms that are less than 2.4 m may use either a single member or a truss type design. The design should be consistent with other nearby mast arm types.

    b. 2.4 m or Greater. Mast arms that are 2.4 m or longer should only use the truss type design.

3. Galvanized Steel Poles. A constant cross section mast arm may be used. The mast arm should be a truss type design, fabrication from a 50-mm diameter steel pipe.

4. Bridges. All mast arms for bridge deck light standards, for all lengths and materials, should use the truss type design.

5. Rise. Figure 78-3B, Mast Arm Rise Versus Length, provides the maximum rise (see Figure 78-3A) that should be used based on the mast arm length.

78-3.04 Luminaires

A luminaire is defined as a complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute light. The following sections and the INDOT *Standard Specifications* provide the Department's criteria for luminaire hardware. Section 78-6.03 discusses the various light distributions for luminaires. For additional information, the designer is encouraged to contact the Design Division's Specialty Project Group for the latest products and specifications.

78-3.04(01) Light Sources

There are numerous light sources for highway lighting. However, there are only a few practical choices when considering availability, size, power requirements and cost effectiveness. Only the high-intensity discharge light sources should be used. The following provides information on the recommended high-intensity light sources that may be used.

1. High Pressure Sodium (HPS). Due to its excellent luminous efficiency, power usage and long life, HPS is the only light source that INDOT is presently using on all new installations of conventional and high-mast lighting. The HPS lamp produces a soft, pinkish-yellow light by passing an electric current through a sodium and mercury vapor.

2. Low Pressure Sodium (LPS). Low pressure sodium is considered one of the most efficient light sources on the market. Its disadvantage is that it requires very long tubes and has poor color quality. INDOT does not allow the use of LPS in State-controlled systems. However, local agencies may consider the use of LPS lighting source. The low pressure sodium lamp produces a yellow light by passing an electrical current through a sodium vapor.

3. Mercury Vapor (MV). Prior to the introduction of HPS, mercury vapor was the most commonly used light source. Local agencies may still desire to install the MV light source for new installations to match existing installations. However, INDOT does not allow the use of MV for conventional or high-mast lighting in any new Department installations. MV usage by INDOT is limited to overhead sign lighting. The mercury vapor lamp produces a bluish-white light.

4. Metal Halide. Metal halide lamps produce better color at higher efficiency than mercury lamps. However, life expectancy for metal halide lamps is shorter than for HPS or MV. They are also more sensitive to lamp orientation than other light sources. Metal halide lamps are commonly used for lighting sports arenas, major sports stadiums, high-mast lighting, downtown areas and parks. Metal halide produces good color rendition. Light is produced by passing a current through a combination of metallic vapors.

78-3.04(02) Optical System

The optical system consists of a light source, a reflector and usually a refractor. The following discusses the optical system of a luminaire.

1. Light Source. Section 78-3.04(01) discusses the recommended high-intensity light sources that should be considered on a project.

2. Reflector. The reflector is one of the devices used in optical control to change the direction of the light rays. Its purpose is to take that portion of light emitted by the lamp that otherwise would be lost or poorly utilized and redirect it to a more desirable distribution pattern. Reflectors are designed to work either alone or with a refractor. Reflectors can be classified into two types, specular and diffused. Specular reflectors are made from a glossy material that provides a mirror-like surface. Diffuse reflectors are used where the intent is to spread the light over a wider area.

3. Refractor. The refractor is another means in optical control to change the direction of the light. Refractors are made of a transparent, clear material, usually high-strength glass or plastic. Plastic is used in high-vandalism areas. However, plastic may yellow over time due to heat and ultraviolet exposure. The refractor, through its prismatic construction, controls and redirects both the light emitted by the lamp and the light reflected off the reflector. It can also be used to control the brightness of the lamp source.

78-3.04(03) Ballasts

All luminaires must include a built-in ballast. Ballasts are used to regulate the voltage to the lamp to ensure that the lamp is operating within its design parameters. It also provides the proper open circuit voltage to start the lamp. INDOT uses the auto-regulator type ballast with an input voltage variation of $\pm$ 10 percent of the rated operating voltage specified. Figure 78-5A, Lamp Data, provides the approximate expected operating wattage for ballasts based on the lamp wattage.

78-3.04(04) Housing Units

Luminaire housing requirements are dependent upon the application type. When selecting luminaire housings for INDOT, the designer should consider the following:

1. Roadway Lighting Luminaire. Roadway lighting luminaire housings and specular reflector holders should be made of aluminum with a weatherproof finish. The housing unit should allow access from the street side and allow for adjustments to the light. The luminaire should also have a high-impact, heat-resistant, glass, prismatic refractor. The unit should be sealed to ensure that dust, moisture and/or insects will not be able to enter the inside of the luminaire.

2. Sign Luminaires. Sign luminaires require the same housing requirements as the roadway lighting luminaires except that they should also provide a durable, plastic, vandal-resistant shield and an aluminum shield that blocks the view of the refractor from approaching motorists. The unit is attached to the sign walkway as shown in the INDOT *Standard Drawings.* The mounting attachment is adjustable to allow for directing the light on the sign.

3. Underpass Luminaires. Underpass luminaires require the same housing requirements as the roadway lighting luminaires except that they should also provide a durable, plastic, vandal-resistant shield. The ballast may be placed as shown in the INDOT *Standard*

Drawings. Underpass luminaires may be attached to the vertical side surface of bridge bent structures or may be suspended by the use of pendants.

4. High-Mast Luminaires. High-mast luminaires are enclosed aluminum units with a reflector and a borsillicate glass refractor. The unit should be sealed to ensure that dust, moisture and/or insects will not be able to enter the inside of the luminaire. The luminaires are attached to the mast ring. The mounting attachment is adjustable to allow for directing the light.

78-3.05 Other Equipment

In developing a highway lighting system, there are numerous components of the equipment design that can affect the design. Many of these elements are addressed in the INDOT *Standard Drawings,* the INDOT *Standard Specifications* and the manufacturer's criteria. Some of these elements include the following:

1. Electrical Components. The above sources discuss many electrical components, including ballasts, fuses, photoelectric controls, wiring, conduit, handholes, connections, breaker boxes, circuit breakers, relay switches, etc.

2. High-Mast Standards. Some of the additional components for high-mast standards include luminaire ring assemblies for attaching luminaires, head frame assemblies, winch assemblies, external drive system used to lower the luminaires for maintenance, cable terminators and lightning rods.

78-4.0 LIGHTING METHODOLOGIES

There are three lighting design methodologies: illuminance methodology, luminance methodology, and small target visibility methodology. For the most part, the Illuminating Engineering Society (IES) of North America has been the leader in the development of these procedures. The following sections briefly describe each methodology. INDOT's present policy is to use only the illuminance methodology in its design of highway lighting. For additional information on these procedures, the designer is encouraged to review the references in Section 78-1.01.

78-4.01 Illuminance

The illuminance methodology is the oldest and simplest to use of the three methodologies. Experience has shown that this design methodology to be very effective. Illuminance is defined as the density of the luminous flux incident on a surface measured in lux. The methodology is concerned with the measurement of the light's intensity striking a particular point on the pavement. The brightest spot will normally occur directly under the luminaire and diminishes the farther the driver is away from the source. The disadvantage of this methodology is that, basically, one does not "see" incident light, but instead sees the light reflected from an object or surface. This sensation is known as "brightness" with objects distinguished by the difference in brightness or "contrast." Brightness can be expressed mathematically as "luminance," the luminous intensity per unit area directed towards the eye.

The important factors in the illuminance design are the measurement of average maintained horizontal illumination (E_h) and the uniformity ratio of the average-maintained illuminance to the minimum-maintained illuminance.

78-4.02 Luminance

Luminance is defined as the luminous intensity of any surface in a given direction per unit of projected area of the surface as viewed from that direction. It is measured in candelas per square meter. The luminance methodology is concerned with the measurement of light from the luminaire reflecting off the pavement surface to the motorist's eyes. This measurement is affected by the pavement's reflectivity characteristics. To obtain the lighting measurements for the roadway, readings are taken from a set of observation points spread across the roadway in a grid pattern. Compared to the illuminance methodology, the luminance design is considered a more accurate representation of the driver's visibility requirements. However, the methodology is significantly more complicated to understand and use. Also, one needs to estimate the pavement reflectivity now and in the future.

The design factors in luminance design include average maintained luminance (L_{avg}), minimum luminance (L_{min}), maximum luminance (L_{max}), maximum veiling luminance (L_v) and ratios of L_{avg} to L_{min}, L_{max} to L_{min}, and L_v to L_{avg}. The Department is presently not using the luminance design for lighting determinations.

78-4.03 Small Target Visibility (STV)

IES has proposed the STV methodology in an effort to better define actual visibility requirements of the driver. The STV methodology is similar to the luminance methodology in measurement of the light's reflectivity but, instead of measuring the pavement's reflectivity, it measures the reflectivity of a 180-mm flat, square target (20 percent diffuse reflectance) against the pavement background. The target is perpendicular to the roadway surface and is always located a fixed distance (83 m) ahead of the observer. The observer's target sight line is parallel to the centerline of the roadway. The STV methodology is significantly more complex than the other methodologies and is considered impossible to calculate manually; i.e., a computer is required. INDOT does not recommend the use of the STV methodology.

78-5.0 DESIGN PROCEDURES

The following sections provide guidelines on the lighting design procedures used by INDOT. Before starting the design process, the designer should contact the Design Division's Traffic Design Unit for INDOT's latest design procedures and criteria. For additional design information, the designer should also review the references in Section 78-1.01.

Lighting system design often requires several iterations to produce an acceptable design. If after the first run the design criteria are not met, the designer will need to change the initial parameters (e.g., pole spacing, mounting heights, luminaire wattage) and recheck the design to determine if it then meets the criteria. This process is repeated until the design is optimized and all criteria are met.

78-5.01 Computerized Design

To determine an acceptable lighting system requires numerous iterations using numerous variables. The chance for error by calculating these equations manually is very high. Therefore, the designer is encouraged to use one of the several commercial computer software packages that are available.

Each software package generally requires the same input and performs the same calculations. However, the method of input may vary significantly. With the proliferation of software programs, the user should check with the Design Division's Specialty Project Group to determine which programs are currently acceptable to INDOT. The Department is currently using the PC-based program ILLUM$, developed by General Electric, for its lighting calculations. ILLUM$ is used to generate templates for design and to check lighting levels and uniformity.

For lighting projects prepared by outside consultants, the consultant should provide the Lighting Unit with the design data (inputs and reports) in both a hard copy format and on an electronic media.

78-5.02 Design Process

The following presents the procedural steps the designer should follow when designing a lighting system.

1. Assemble Information. Assemble all necessary information. This includes the following:

a. contacting the Lighting Unit in the Traffic Design Section for the current design policies and procedures applicable to the project, the latest copies of sample plans, schedules, pay quantities, plan notes and example calculations;

b. gathering roadway and bridge plans including plan and profile sheets and special details sheets (e.g., overhead signs);

c. determining existing and expected utility locations;

d. discussing any special considerations with the highway or bridge designer;

e. conducting field reviews; and

f. talking with local officials for local projects.

2. <u>Determine Classifications</u>. Determine the roadway classification and environmental conditions. If not already included in the project report, this information can be obtained from the Preliminary Engineering Studies Section. The roadway classifications, for lighting purposes, are defined in Section 78-6.01.

3. <u>Select Design Criteria</u>. Based on the above information, the designer will select the pertinent design methodology (see Section 78-4.0) and the appropriate criteria based on the classification selected in Step 2; see Section 78-6.02. For INDOT lighting projects, only the illuminance design methodology should be used.

4. <u>Select Equipment</u>. In the preliminary design, the designer will need to make some initial assumptions on the equipment composition. This includes mounting heights, pole setback distances, light sources, mast-arm lengths, lamp wattage, etc. INDOT's practice is to typically use 12-m poles with 250-W or 400-W HPS lamps. Figure 78-5A, Lamp Data, provides the information on lighting levels for various lighting sources. See Sections 78-3.0 and 78-6.03 for additional details on equipment selection. After selecting the luminaire equipment, the designer will also need to obtain the photometric data sheet from the manufacturer for the luminaire(s) selected.

5. <u>Select Layout Arrangement</u>. Section 78-6.04 provides information on the commonly used lighting arrangements. The selection of the appropriate layout design depends upon local site conditions and the engineer's judgment. Section 78-6.05 presents the roadside safety considerations when selecting the lighting arrangements. Section 78-6.06 provides other layout considerations.

6. Luminaire Spacings. For INDOT roadway lighting projects, use the illuminance methodology to determine the appropriate luminaire spacing. Typically this step is conducted by the computer. For hand calculations, Equation 78-5.1 should be used. Sections 78-1.02 and 78-6.03 define the various factors used in the equation.

$$S = \frac{LL \ x \ CU \ x \ LLD \ x \ LDD}{E_h \ x \ W} \qquad \text{(Equation 78-5.1)}$$

Where:	S	=	Luminaire Spacing (m)
	LL	=	Initial Lamp Lumens
	CU	=	Coefficient of Utilization
	LLD	=	Lamp Lumen Depreciation Factor
	LDD	=	Lamp Dirt Depreciation Factor
	E_h	=	Average Maintained Level of Illumination (lx)
	W	=	Width of Lighted Roadway (m)

7. Check Uniformity. Once the spacing has been determined, the designer will check the uniformity of light distribution and compare this to the criteria selected in Step 3. Use Equation 78-5.2 to determine the uniformity ratio. Section 78-7.0 provides an example for calculating the uniformity ratio.

$$Uniformity\ Ratio = \frac{Average\ Maintained\ Illumination\ Value}{Minimum\ Maintained\ Illumination\ Value} \qquad \text{(Equation 78-5.2)}$$

8. Select Optimum Design. Because recalculations by computer are relatively quick and easy, the designer should try several alternatives even if one design meets the criteria. There are often several alternatives that will work.

9. Electrical Design. Once the number, sizes and locations of the luminaires are determined, the designer will need to determine the appropriate electric voltage drop for the system. Section 78-6.07 provides information on how to determine the voltage drop for the lighting system.

10. INDOT's Pre-design Approval. For consultant projects, the consultant should discuss the optimum alternatives with the Lighting Unit prior to preparing the plans in order to expedite project development. Upon approval from INDOT, FHWA (if necessary) and the local utility company, the final development of the plans may proceed.

11. Prepare Plans. Once the final design has been selected, the lighting designer will prepare and submit to the Lighting Unit the plan sheets, quantities and notes, cost estimate,

voltage drop calculations, circuit schematic layouts, and any special provisions that are required for review.

78-6.0 DESIGN CONSIDERATIONS

In designing a lighting system, there are many elements or factors the designer must consider. To help the designer in this process, the IES has standardized many of these elements. However, not all elements are appropriate to Indiana. In addition to the following Figure 78-6A, INDOT Lighting Design Parameters, provides guidance on the typical design values used by INDOT for lighting designs.

78-6.01 Roadway Classifications

In selecting the appropriate design criteria, the designer must determine the highway functional classification (Section 78-5.02, Step 2). The following definitions are used to define roadway classifications for highway lighting purposes only.

1. Freeway. A divided major roadway with full control of access and with no crossings at grade. This definition applies to toll and non-toll roads. An Interstate highway is a freeway.

2. Expressway. A divided major roadway for through-traffic with partial control of access and generally with interchanges at major crossroads. Expressways for noncommercial traffic within parks and park-like areas are usually considered parkways.

3. Arterial. That part of the roadway system which serves as the principal network for through-traffic flow. These routes connect areas of principal traffic generation and important rural highways entering the city. For INDOT projects, use the city street design criteria.

4. Collector. The distributor and collector roadways servicing traffic between arterials and local roadways. These are roadways used mainly for traffic movements within residential, commercial and industrial areas. For INDOT projects, use the city street design criteria.

5. Local. Roadways used primarily for direct access to residential, commercial, industrial or other abutting property. They do not include roadways carrying through traffic. Long local roadways will generally be divided into short sections by collector roadway systems. For INDOT projects, use the city street design criteria.

6. Sidewalk. Paved or otherwise improved areas for pedestrian use, located within public street rights-of-way which also contain roadways for vehicular traffic.

7. Pedestrian Walkway. A public walk for pedestrian traffic not necessarily within the right-of-way for a vehicular traffic roadway. Included are skywalks (pedestrian overpasses), subwalks (pedestrian tunnels), walkways giving access to parks or block interiors and midblock street crossings.

8. Isolated Interchange. A grade-separated roadway crossing, which is not part of a continuously lighted system, with one or more ramp connections with the crossroad.

9. Isolated Intersection. The general area where two or more non-continuously lighted roadways join or cross at the same level. This area includes the roadway and roadside facilities for traffic movement in that area. A special type of isolated intersection is the channelized intersection in which traffic is directed into definite paths by islands with raised curbing.

10. Bikeway. Any road, street, path or way that is specifically designated as being open to bicycle travel, regardless of whether such facilities are designed for the exclusive use of bicycles or will be shared with other transportation modes.

    a. Type A: Designated Bicycle Lane. A portion of roadway or shoulder which has been designated for use by bicyclists. It is distinguished from the portion of the roadway for motor vehicle traffic by a paint stripe, curb or other similar device.

    b. Type B: Bicycle Path. A separate trail or path from which motor vehicles are prohibited and which is for the exclusive use of bicyclists or the shared use of bicyclists and pedestrians. Where such a trail or path forms a part of a highway, it is separated from the roadway for motor vehicle traffic by an open space or barrier.

78-6.02 Design Criteria

The lighting criteria varies according to the design methodology, highway classification, area classification and pavement type. The following figures present AASHTO and INDOT lighting design criteria:

1. Figure 78-6B presents the recommended INDOT roadway illuminance design criteria.

2. The AASHTO *An Informational Guide for Roadway Lighting* presents the recommended illuminance design criteria for pedestrian walkways and bikeway paths and non-INDOT projects.

78-6.03 Equipment Considerations

Figure 78-6C, Luminaire Geometry, illustrates the common terms used in defining and designing luminaires (e.g., mounting heights, overhang, rotation). The following sections discuss other equipment considerations for design.

78-6.03(01) Light Distribution

In determining the lighting design layout, the designer must know the expected light distribution for the luminaire. Designers may obtain photometric data from luminaire manufacturers. The proper distribution of light from the luminaire is a major factor in the design of efficient lighting. Figure 78-6D, Luminaire Classification System, presents three IES classifications for luminaire light distributions: width, spacing, and glare control. Figure 78-6E, Guide for Luminaire Lateral Light Type and Placement, provides additional guidance on the selection of luminaires based on these classifications. Figure 78-6F, Plan View for Luminaire Coverages, illustrates a plan view of a roadway which has been modified to present a series of Longitudinal Roadway Lines (LRL) and Transverse Roadway Lines (TRL) and how these distribution factors are interrelated to each other. The following briefly describes these classifications.

1. Vertical Light Distribution. There are three groups of vertical light distribution — short, medium and long. The selection of a vertical light distribution is dependent upon the mounting height and light source. Pavement brightness is generally increased when the vertical light angle is increased. The following defines the three vertical light distribution types.

    a. Short Distribution. The maximum luminous intensity strikes the roadway surface between 1 and 2.25 mounting heights from the luminaire. The theoretical maximum spacing, using the short distribution, is 4.5 mounting heights.

    b. Medium Distribution. The maximum luminous intensity is between 2.25 and 3.75 mounting heights from the luminaire. The theoretical maximum spacing is 7.5 mounting heights. This is generally the most commonly used distribution type.

    c. Long Distribution. The maximum luminous intensity is between 3.75 and 6.0 mounting heights from the luminaire. The theoretical maximum spacing is 12 mounting heights.

2. <u>Lateral Light Distributions</u>. The IES has developed seven lateral light distributions which are presented in Figure 78-6F. In addition, the following provides information on the placement for these lateral light distributions.

   a. Type I. The luminaire is placed in the center of the street or area where lighting is required. It produces a long, narrow, oval-shaped lighted area. Some types of high-mast lighting are also considered a modified form of Type I.

   b. Type I, 4-Way. The luminaire is placed in the center of the intersection and distributes the lighting along the four legs of the intersection. This type generally applies to high-mast lighting.

   c. Type II. The luminaire is placed on the side of the street or edge of the area to be lighted. It produces a long, narrow, oval-shaped lighted area which is usually applicable to narrower streets.

   d. Type II, 4-Way. The luminaire is placed at one corner of the intersection and distributes the lighting along the four legs of the intersection.

   e. Type III. The luminaire is placed on the side of the street or edge of area to be lighted. It produces an oval-shaped lighted area and is usually applicable to medium width streets.

   f. Type IV. The luminaire is placed on the side of the street or edge of area to be lighted. It produces a wider, oval-shaped lighted area and is usually applicable to wide streets.

   g. Type V. The luminaire is placed in the center of the street, intersection or area where lighting is required. It produces a circular, lighted area. Type V often applies to high-mast lighting.

3. <u>Control of Distribution</u>. As vertical light angles increase, discomforting glare also increases. To distinguish the glare effects on the driver from the light source, IES has defined the glare effects as follows:

   a. Cutoff. The cutoff design is where the luminaire light distribution is less than 25,000 lm at an angle of 90^{o} above nadir (vertical axis) and 100,000 lm at a vertical angle of 80^{o} above nadir.

   b. Semi-cutoff. For the semi-cutoff design, the luminous flux numbers become 50,000 lm for 90^{o} above nadir and 200,000 lm at a vertical angle of 80^{o} above nadir. This control distribution is the typical distribution INDOT uses for its lighting designs.

c. Non-cutoff. This classification is where there is no limitation on the zone above the maximum luminous intensity.

78-6.03(02) Mounting Heights

Higher wattage bulbs allow the designer to use higher mounting heights, fewer luminaires and fewer support poles and still maintain the lighting quality. In general, higher mounting heights tend to produce the most efficient design. For practical and aesthetic reasons, the mounting height should remain constant throughout the system. The manufacturer's photometric testing results are required to determine the appropriate adjustments for mounting heights.

78-6.03(03) Coefficient of Utilization

The coefficient-of-utilization curve defines the percentage of bare lamp lumens that are used to light the desired surface. Figure 78-6G illustrates a sample coefficient-of-utilization curve. This curve and the isolux diagram are used to determine the amount of illumination to any point on the pavement. The curve provides values for both the street side of the luminaire and the house side. If the luminaire is located over the roadway, then the house side numbers should also be used to determine the level of illumination. The manufacturer is required to provide these charts with their photometric testing results.

78-6.03(04) Light Loss Factors (Maintenance Factor)

The efficiency of the luminaire is reduced over time. The designer must estimate this reduction to properly estimate the light available at the end of the lamp maintenance life. The maintenance factor may range from 0.50 - 0.90, with the typical range between 0.65 - 0.75. Figure 78-6A, INDOT Lighting Design Parameters, presents the typical factors used by INDOT for designing lighting systems. The maintenance factor is the product of the following factors.

1. Lamp Lumen Depreciation Factor (LLD). As the lamp progresses through its service life, the lumen output of the lamp decreases. This is an inherent characteristic of all lamps. The initial lamp lumen value is adjusted by a lumen depreciation factor to compensate for the anticipated lumen reduction. This assures that a minimum level of illumination will be available at the end of the assumed lamp life, even though lamp lumen depreciation has occurred. This information should be provided by the manufacturer. For design purposes, a LLD factor of 0.90 should be used. If deemed

necessary, other values may only be used with approval from the Design Division’s Specialty Project Group.

2. <u>Luminaire Dirt Depreciation Factor (LDD)</u>. Dirt on the exterior and interior of the luminaire, and to some extent on the lamp, reduces the amount of light reaching the roadway. Various degrees of dirt accumulation may be anticipated depending upon the area in which the luminaire is located. Industry; exhaust of vehicles, especially large diesel trucks; dust; etc., all combine to produce the dirt accumulation on the luminaire. Higher mounting heights, however, tend to reduce the vehicle-related dirt accumulations. Information on the relationship between the area and the expected dirt accumulation is shown in Figure 78-6H. For INDOT design purposes, a LDD factor of 0.87 should be used. This is based on a moderately dirty environment and three years exposure time. If deemed necessary, other values may only be used with approval from the Design Division’s Specialty Project Group.

78-6.04 Systems Configurations

Figure 78-6 I, Lighting System Configurations ,illustrates the typical layout arrangements used by INDOT for its lighting system designs. Figure 78-6 I also illustrates the recommended illuminance calculation points for the various arrangements (Section 78-5.02, Step 7). INDOT typically does not place light standards in the median for the following reasons.

1. In medians without barriers, the light standards can be struck by traffic in both directions.

2. In medians with concrete median barriers, the light standards are typically placed on the top of the barrier. Studies have shown that trucks and buses hitting the concrete median barrier will lean substantially over the barrier and may strike the light standard.

3. Maintenance of the luminaire in the median can be a safety concern for the maintenance crew and truck near the high-speed lanes.

Figure 78-6J illustrates a typical layout for partial lighting of an interchange.

78-6.05 Roadside Safety Considerations

The placement of light poles (or standards) should be installed so that they will not reduce roadside safety. However, the physical roadside conditions often dictate the placement of light poles. It is important that the designer evaluate these limitations in the design process. Overpasses, sign structures, guardrail, roadway curvature, right-of-way limitations, gore clearances, the proximity of other existing roadside obstacles and the limitations of the lighting equipment are all factors that must be considered in design. The designer also must consider many other factors such as the roadway and area classification, design speed and/or posted speed limit, safety, aesthetics, economics environmental impacts, etc., while accounting for the physical limitations.

There should be adequate right-of-way, driveway control and utility clearance to allow the placement of the proposed lighting system according to these safety requirements. Otherwise, additional right-of-way, driveway control and/or utility relocations may be required. The designer should consider the following when determining the location of light poles relative to roadside safety:

1. <u>Breakaway</u>. All conventional light poles placed within the clear zone or the obstruction-free zone will be provided with a breakaway device except at locations with sidewalks. In addition, the designer should consider the following:

    a. Pedestrians. Poles located in an area where pedestrian traffic exists or is expected should not be mounted on a breakaway device, this includes rest areas.

    b. Supports. Any substantial remains of the breakaway lighting support that will remain after the unit has been struck will have a maximum projection of 100 mm (see Figure 78-6K, Breakaway Support Stub Clearance Diagram).

    c. Breakaway Device. All breakaway devices will comply with all applicable AASHTO requirements for structural supports and may be one of the several forms that have been approved for use as a breakaway device; see Section 78-3.0.

    d. Wiring. All poles that require a breakaway device should be served by underground wiring and should be designed with breakaway connections.

2. <u>Grading</u>. The location of all breakaway light standards (except those shielded by guardrail) should not be in areas where the opportunity exists for them to be struck more than 230 mm above the normal point of vehicular bumper impact. Normal bumper height is 460 mm. To avoid light standards being struck at an improper height, they should be placed, and the area around them graded as shown in the INDOT *Standard Drawings*, as follows:

    a. Fill Slopes Flatter than 6:1. For these fill slopes, there are no restrictions on placement of the light standard nor is any special grading required. Generally, light standards should be placed 6.0 m from the edge of the travel lane or 3.0 m from the edge of shoulder.

b. Fill Slopes from 5:1 to 6:1. The grading plans as shown in the INDOT *Standard Drawings* should be followed. Generally, light standards should be placed 6.0 m from the edge of the travel lane or 3.0 m from the edge of shoulder.

c. Fill Slopes 4:1 or Steeper. Light standards should be offset 1.0 m from the edge of shoulder or 3.6 m from the edge of the travel lane, whichever is greater. Grading should be provided as shown on Figure 78-6L, Light Standard Treatment (Fill Slopes 4:1 or Steeper).

d. All Cut Slopes. The grading plans as shown in the INDOT *Standard Drawings* should be used to determine the placement of light standards on cut slopes.

3. <u>Gore Areas</u>. Poles should be located to provide adequate safety clearance in the gore areas of the exit and entrance ramps, typically a minimum of 15 m (see Figure 78-6M, Pole Clearances for Ramp Gores).

4. <u>Horizontal Curves</u>. Poles should desirably be placed on the inside of sharp curves and loops.

5. <u>Maintenance</u>. When determining pole locations, the designer should consider the hazard which will be encountered while performing future maintenance on the lighting equipment.

6. <u>Barriers</u>. The placement of light standards in conjunction with roadside barriers should be designed to meet the criteria provided in Section 49-5.0. In addition, the designer should consider the following:

   a. Placement. All light standards should be placed behind the barrier.

   b. Deflection. Poles behind guardrail should be offset by at least the deflection distance of the guardrail (see Section 49-5.01). This will allow the railing to deflect without hitting the pole. If this clearance distance is not available, such as in extreme side slope conditions or if the pole is located within the approach end of the railing, a breakaway device should be added. INDOT's practice is to always use breakaway devices, even behind guardrail.

   c. Concrete Median Barriers. Poles that are shielded by a rigid or non-yielding barrier type will not require a breakaway device. However, it is INDOT's practice to always use breakaway devices, even behind these rigid or non-yielding barrier types.

   d. Impact Attenuators. Poles, either with or without breakaway devices, should be located such that they will not interfere with the functional operation of any impact attenuator or other safety breakaway device.

7. Protection Features. Special features, such as a curb, barrier or other obstacles constructed primarily to protect a light pole, should not be used.

8. Mast Towers. Unprotected high-mast towers should desirably be at least 25 m from the nearest edge of the mainline or ramp travel lane. The minimum clear distance will be the roadway clear zone through the area where the high-mast lighting is located. Access for service vehicles should be provided for high-mast towers and service poles.

9. Existing Installations. Existing breakaway light standards should be evaluated to determine if it is necessary to relocate them, regrade around the bases, or upgrade the breakaway mechanism to current criteria. The determination of the work necessary on existing breakaway light standards involves a review of numerous variables. Therefore, this decision must be made by the Design Division's Specialty Project Group, Lighting Engineer. If Federal-aid funds will be used for construction and the project is on the National Highway System and is not exempt from FHWA oversight, the FHWA should also be consulted.

78-6.06 Other Considerations

In addition to all other considerations, the designer should review the following when determining the design of a lighting system.

1. Signs. Poles should be placed to minimize interference with the driver's view of the roadway and highway signs. The luminaire brightness should not seriously detract from the legibility of the sign at night.

2. Overhead Signs. Existing overhead sign lights should be tied into any new lighting system circuits.

3. Structures. Poles should be placed sufficiently far enough away from overhead bridges or overhead sign structures so that the light from the luminaire will not cast distracting shadows on the roadway surface or produce unnecessary glare for the motorist.

4. Trees. Trees should be sufficiently pruned so that they do not cause shadows on the roadway surface or reduce the luminaire's efficiency. The luminaire should be designed with the proper height and mast-arm lengths to reflect the effect trees will have on lighting distribution.

5. <u>Retaining Walls</u>. Poles may be located either on top of or behind retaining walls. Poles mounted on top of retaining walls will require special consideration for the retaining wall design.

6. <u>Medians</u>. Although not desirable, poles may be placed in median locations where the width of the median is appropriate or if median barriers will be used. Normally, the median width should be equal to or greater than the pole mounting height. Where used, twin poles should have the same mast-arm lengths on each side.

78-6.07 Voltage Drop Determinations

The typical highway lighting distribution circuit consists of two 240-volt circuits provided by a multiple conductor armored cable. Power supply to the lighting system is normally 240/480 volt, single phase, 60-cycle alternating current. The lights are alternately connected to each side of the four-wire circuit. Ground rods are provided at every light standard. Voltage drop should not be over 10 percent to the last light in the circuit. Figure 78-6N provides the design amperes for various luminaires. Figure 78-6 O provides resistancances for various wire types. Equation 78-6.1 should be used to determine the voltage drop between two adjacent luminaires.

$$E = IR \qquad \text{(Equation 78-6.1)}$$

Where:

E = voltage (volt)
I = current (ampere)
R = resistance (ohm)

The following example illustrates how to calculate voltage drop for a lighting system.

* * * * * * * * * *

<u>Example 78-6.1</u>

Given: Figure 78-6P, Voltage Drop Calculations (Example 78-6.1), illustrates a single-phase, three-wire balanced load circuit. The circuit includes eight 400 W HPS roadway luminaires with a branch circuit to two 250 W MV sign luminaires. The wire for roadway luminaires is #4 copper and to the sign luminaires #10 copper.

Problem: Determine the voltage drop of the circuit and the percent voltage drop to the last lamp.

Solution: Working from the last luminaire on each branch, the voltage drop can be determined for each circuit branch using Equation 78-6.1 and Figures 78-6N and 78-6 O.

1. Determine the voltage drop for Branch Circuit A:

Luminaire #9 to Luminaire #7	$E_9 = 2.0 \times 0.0010105 \times 60 = 0.1212$ V
Luminaire #7 to Luminaire #5	$E_7 = 4.0 \times 0.0010105 \times 60 = 0.2425$ V
Luminaire #5 to Luminaire #3	$E_5 = 6.0 \times 0.0010105 \times 60 = 0.3638$ V
Luminaire #3 to Luminaire #1	$E_3 = 8.0 \times 0.0010105 \times 60 = 0.4850$ V
Luminaire #1 to Service Point	$E_1 = 10.0 \times 0.0010105 \times 90 = 0.9095$ V

Total voltage drop for Branch Circuit A:

0.1212 + 0.2425 + 0.3638 + 0.4850 + 0.9095 = 2.1220 V

2. Determine the voltage drop for Branch Circuit B:

Luminaire #8 to Luminaire #6	$E_8 = 2.0 \times 0.0010105 \times 60 = 0.1212$ V
Luminaire #6 to Point H	$E_6 = 4.0 \times 0.0010105 \times 45 = 0.1819$ V
Luminaire #11 to Luminaire #10	$E_{11} = 1.4 \times 0.0040682 \times 4 = 0.0228$ V
Luminaire #10 to Point H	$E_{10} = 2.8 \times 0.0040682 \times 15 = 0.1709$ V
Point H to Luminaire # 4	$E_H = 6.8 \times 0.0010105 \times 15 = 0.1031$ V
Luminaire #4 to Luminaire #2	$E_4 = 8.8 \times 0.0010105 \times 60 = 0.5335$ V
Luminaire #2 to Service Point	$E_2 = 10.8 \times 0.0010105 \times 135 = 1.4733$ V

Total voltage drop for Branch Circuit B:

0.1212 + 0.1819 + 0.0228 + 0.1709 + 0.1031 + 0.5335 + 1.4733 = 2.6067 V

3. Determine the percent voltage drop:

From observation, Branch Circuit B has the most critical voltage drop 2.6067 V versus 2.1220 V.

$$\frac{2.6067}{240} \times 100\% = 1.086\%$$

This design is well within the allowable 10% voltage drop.

* * * * * * * * * *

78-7.0 HIGH-MAST LIGHTING DESIGNS

In general, the design of high-mast lighting systems consists of the same design procedures as discussed in Section 78-5.02. In addition, the designer should consider the following:

1. Lighting Source. Generally, a 1000-W high pressure sodium light source should be used. The number of luminaires required will be determined by the area to be lighted. As a general starting point, it can be assumed that mounting heights of 30 m will require 400,000 lm, 600,000 lm for mounting heights of 35 m to 40 m, and 800,000 lm for mounting heights of 45 m. The number of luminaires per pole typically ranges from 4 to 6 luminaires per pole.

2. Mounting Heights. High-mast lighting can range from 24 m to 60 m. In general, heights of 30 m to 50 m have proved to be the most practical. Greater heights require more luminaires to maintain illumination levels. However, greater heights allow for fewer poles and provide better uniformity.

3. Location. In determining the location for high-mast poles, the designer should review the plan view of the area to determine the more critical areas requiring lighting. In selecting the appropriate luminaire supports for high-mast lighting, the designer should consider the following:

    a. Critical Areas. Mast poles should be located so that the highest localized levels of illumination fall within the critical traffic areas (e.g., freeway/ramp junctions, ramp terminals, merge points).

    b. Roadside Safety. Mast poles should be located a sufficient distance from the roadway so that the probability of a collision is virtually eliminated. They also should not be placed on the end of long tangents.

    c. Signs. Masts should be located so that they are not within the driver's direct line of sight to highway signs.

4. Design. There are generally two methodologies for checking the adequacy of uniformity: the point-by-point method and the template method. The point-by-point method checks illumination by using the manufacturer’s isolux diagram. The total illumination at a point is determined by the sum of the contributions of illumination from all mast assemblies within the effective range of the point. Due to the numerous calculations, a computer should be used to make these determinations. The template methodology uses isolux templates to determine the appropriate locations for mast supports. The templates may be moved around to ensure that the minimum-maintained illumination is provided

and uniformity ratio has been met. Section 78-8.0 provides an example of using the template methodology for high-mast lighting design.

78-8.0 EXAMPLE COMPUTATIONS

The following examples are provided to illustrate how to manually determine lighting systems using the illuminance design. Example 78-8.1 illustrates a roadway lighting design using conventional lighting standards. Example 78-8.2 illustrates the template methodology for high-mast lighting. Although these examples use the manual calculation procedures, a computer should be used to design the lighting system.

* * * * * * * * * * *

Example 78-8.1

Given: An urban collector through a commercially developed area.

Problem: Design a lighting system.

Solution: Using the steps presented in Section 78-5.02 and the design considerations in Section 78-6.0, the design should proceed as follows:

1. Assemble Information. Plan and profile sheets are provided by the roadway designer. A field review is held with local officials on-site. From the plans the following information is determined.

   Roadway Width: 18 m (Four 3.6-m wide lanes with a 3.6-m wide two-way left-turn lane in the median) (see Figure 78-8A, Urban Collector Highway (Example 78-8.1)).

   Design Speed: 70 km/h

   Surface Type: Bituminous pavement with 150-mm concrete curbs on both sides

   Pedestrians: No pedestrians are expected near the roadway

   Terrain: Generally flat

2. Determine Classifications. Using the data collected in Step 1 and Section 78-6.01, the roadway classification is a collector/city street.

3. Select Design Criteria. From Figure 78-6B, INDOT Illuminance Design Criteria, the lighting design should meet the following criteria:

   Average Illuminance (E_h) = 9 lx
   Uniformity Ratio = 4:1

4. Select Equipment. The equipment is selected as follows:

   Light Source = 400-W HPS (Figure 78-6A, INDOT Lighting Design Parameters)
   Mounting Height (MH) = 12 m (Figure 78-6A)
   Mast Arm Length = 3.0 m
   Luminaire Distribution = Medium Distribution, Type II, Semi-cutoff glare control (M-S-II)
   Effective Mounting Height = 12 m
   Initial Lamp Lumens (LL) = 50,000 (Figure 78-5A, Lamp Data)
   Coefficient of Utilization (CU) = 0.48 (Manufacturer's Data - Figure 78-8B, Coefficient-of-Utilization Curve (M-S-II Luminaire))
   Lamp Lumen Depreciation Factor (LLD) = 0.90 (Section 78-6.03(04))
   Luminaire Dirt Depreciation Factor (LDD) = 0.87 (Section 78-6.03(04))

5. Select Layout. The roadway width to mount height ratio is 18/12 = 1.5 From Figure 78-6E, Guide for Luminaire Lateral Light Type and Placement, use a Type II with a staggered arrangement. Due to right-of-way restrictions, the poles can only be placed 3.0 m behind the curb.

6. Determine Luminaire Spacings. Using Equation 78-5.1, the luminaire spacing can be determined as follows:

$$S = \frac{(LL)(CU)(LLD)(LDD)}{(E_h)(W)}$$

$$S = \frac{(50{,}000)(0.48)(0.90)(0.87)}{(9)(18)}$$

$$S = 116\ m$$

7. Check Uniformity. Using Equation 78-5.2, the manufacturer's isolux diagram (Figure 78-8C, Sample Isolux Diagram (Example 78-8.1)), and Figure 78-6 I, Lighting System Configurations, the following steps are used to check the lighting uniformity.

   a. Setup. The roadway geometrics are superimposed on the isolux diagram. With the 3.0-m mast arm length, the luminaire is directly over the curb line. The curb line can be placed on the line directly below the luminaire (the 0 line). The lateral width of the roadway is 18 m and the mounting height is 12 m, the lateral (or transverse) ratio is 18/12 = 1.5. This is marked opposite of the curb line on the isolux diagram.

b. Determine Checkpoints. From Figure 78-8A, determine the necessary checkpoints (S = 116 m).

c. Determine Contributing Luminaries. For a staggered arrangement, the lighting levels need only be checked for the selected luminaire and the luminaries directly opposite of the luminaire on both sides. Lighting levels from other luminaires will have a minimal effect and, therefore, are not considered.

d. Determine Transverse and Longitudinal Ratios. The ratios for each of the three luminaires are shown in Figure 78-8D, Unadjusted Illumination Values (Example 78-8.1). These ratios are determined by measuring the distance and dividing them by the mounting height.

e. Determine Illumination Levels. Using the ratios determined in Step 7d. and the isolux diagram in Figure 78-8C, the illumination levels are determined and shown in Figure 78-8D. From Figure 78-8D, the critical location is found to be at Point B (0.03 lx).

f. Adjust Minimum Levels. The values shown in Figure 78-8D are based on 1000 initial lamp lumens, 9-m mounting height, and clean lamps. Therefore, Point B must be adjusted as follows:

LL	=	50 (50,000 Initial Lamp Lumens, Step 4)
MH	=	0.58 (Figure 78-8C)
LLD	=	0.90 (Step 4)
LDD	=	0.87 (Step 4)
E_h	=	(0.03)(50)(0.58)(0.90)(0.87) = 0.68 lx

g. Determine Uniformity Ratio. Using Equation 78-5.2, the uniformity ratio is determined as follows:

$$\text{Uniformity Ratio} = \frac{9}{0.68} = 13:1$$

This ratio is greater than the 4:1 maximum criteria determined in Step 3; therefore, this design arrangement would not be acceptable.

8. <u>Optimize Design</u>. From Step 7, it can be seen that the design would not meet the light illumination criteria. However, if this design did meet these criteria it may not be the

most cost-effective design. Typically, two or three runs assuming different mounting heights, spacings, wattages, etc., should be performed to determine the most efficient design. In general, the system with the highest mounting height and longest spacing will provide the most cost-effective design.

<u>Example 78-8.2</u>

Given: An urban cloverleaf interchange (see Figure 78-8E, Urban Interchange Lighting).

Problem: Design a lighting system using high-mast lighting and the template methodology.

Solution: Using the steps presented in Section 78-5.02 and the design considerations in Sections 78-6.0 and 78-7.0, the design should proceed as follows:

1. <u>Assemble Information</u>. Plan and profile sheets are provided by the roadway designer. A field review is held on-site. From the plans the following information is determined:

   Area - 900,000 m^2 (see Figure 78-8E)

   Design Speed: 110 km/h

   Surface Type: Concrete pavement with concrete shoulders

   Terrain: Generally flat

   Clear Zone: 9.0 m (see Figure 49-2A)

2. <u>Determine Classifications</u>. Using the data collected in Step 1 and Section 78-6.01, the roadway classification is a freeway.

3. <u>Select Design Criteria</u>. From Figure 78-6B, INDOT Illuminance Design Criteria, the lighting design should meet the following criteria.

   Average Illuminance (E_h) = 8 lx
   Uniformity Ratio = 4:1

4. <u>Select Equipment</u>. The equipment is selected as follows:

   Light Source = 1000-W HPS (Section 78-7.0)
   Mounting Height (MH) = 30 m (assumed)
   Luminaire Distribution = Short Distribution, Type V, Cutoff glare control (S-C-V)

Effective Mounting Height = 30 m
Initial Lamp Lumens (LL) = 140,000
Lamp Lumen Depreciation Factor (LLD) = 0.90 (Section 78-6.03(04))
Luminaire Dirt Depreciation Factor (LDD) = 0.87 (Section 78-6.03(04))

5. Design Template. A template is required which shows the minimum-initial illumination required from one luminaire with a perimeter of one-half that value. The following steps are used.

a. Determine the Minimum-Maintained Illumination (MMI):

$$MMI = \frac{Average\ Maintained\ Illumination}{Average\text{-}to\text{-}Minimum\ Ratio} = \frac{8\ \ lx}{4:1} = 2\ \ lx$$

b. Determine the Minimum-Initial Illumination (MII):

$$MII = \frac{MMI}{(LLD)(LDD)} = \frac{2}{(0.90)(0.87)} = 2.55\ \ lx$$

c. Determine the MII from one luminaire. Assume 4 luminaires per pole.

$$MII\ /\ Luminaire = \frac{MMI}{No.\ Luminaires\ /\ pole} = \frac{2.55\ \ lx}{4} = 0.64\ \ lx$$

d. Typically, at least two poles will contribute to the minimum illumination.

$$1/2\ MII\ /\ Luminaire = (1/2)(0.64) = 0.32\ \ lx$$

e. From the isolux diagram for a 1000-W HPS Luminaire (see Figure 78-8F), the MII per luminaire and 2 MII per luminaire distances are determined.

Note: If the mounting height selected for the installation differs from that on the photometric test report, the proper correction factor has to be applied. Also, if the values on the test report are per 1000 lamp lumens, a factor for actual initial lamp lumens has to be included in the computations.

f. Using the longitudinal- or transverse-distance-to-mounting-height ratio of the isolux diagram as scale, make a template to fit the scale of the plans used for the lighting layout. Use 2 MII / luminaire as the perimeter of the template and show MMI / luminaire as a broken line on the template.

6. Determine Pole Locations. Start by placing the poles at the critical points. For interchanges, this is typically the gore areas. Note that the poles should desirably be placed at least 25 m from the edge of the mainline travel lane. The minimum clear zone distance will be acceptable (see Figure 78-8G, Interchange Lighting Layout (Example 78-8.2)).

7. Determine the Coefficient of Utilization. Using the 2 MII / luminaire line in Figure 78-8F, the coefficient of utilization can be determined (CU = 0.25). For Type V light distributions, the values for both street and house sides are the same. Because the house and street sides are fully utilized, the CU value can be doubled (CU = 0.50).

8. Determine Average-Maintained Illumination (AMI).

$$AMI = \frac{(No.\ Poles)(LL)(CU)(LLD)(LDD)(3.2796)}{Total\ Area}$$

From Step 6, 9 poles were used; therefore:

$$AMI = \frac{(9)(140{,}000)(0.50)(0.90)(0.87)(3.2796)}{900{,}000\ m^2} = 1.80\ \ lx$$

9. Check Minimum-Maintained Illumination (MMI). The designer must check the layout to ensure the minimum requirements are met. This will involve checking several points where the lowest illumination levels appear to be. The actual values are determined using Figures 78-8F and 78-8G. Figure 78-8H, Unadjusted Illumination Values (Example 78-8.2), provides the illumination calculations for several selected points. The critical location is found to be at Point B (0.68 lx). This value must be adjusted by the light loss factors as follows:

MMI = (0.68)(0.90)(0.87) = 0.53 lx

10. Determine Uniformity Ratio. Using Equation 78-5.2, the uniformity ratio is determined as follows:

$$Uniformity\ Ratio = \frac{1.80}{0.53} = 3.40 : 1$$

This ratio is less than the 4:1 maximum criteria determined in Step 3; therefore, this design arrangement would be acceptable.

11. Final Check. Because 4 luminaires per pole were assumed, the average-maintained illumination would be as follows:

$(4)(1.80) = 7.20$ lx

* * * * * * * * * *